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Location Memory in 8-Month-Old Infants in a Non-Search AB Task: Further Evidence

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When an object is hidden in a location A and then in a location B, 8-month-old infants tend to search in A if forced to wait 3 s before retrieving the object, and to search randomly in A or B if forced to wait 6 s before retrieving the object (Diamond, 1985). Most investigators have attributed infants' perseverative and random search errors to some immature memory mechanism (e.g., Bjork & Cummings, 1984; Harris, in press; Kagan, 1974; Schacter, Moscovitch, Tulving, McLachlan, & Freedman, 1986; Sophian & Wellman, 1983; Wellman, Cross, & Bartsch, 1987). Baillargeon and Graber (1988) recently tested this hypothesis. They reasoned that if infants' search errors reflect memory difficulties, infants should perform poorly in *any* task requiring them to keep track of changes in an object's hiding place. The task Baillargeon and Graber devised was a non-search task. In this task, an object was hidden behind one of two screens; after 15 s, a hand retrieved the object from behind the correct screen (possible event) or from behind the incorrect screen (impossible event). The results indicated that the infants still remembered the object's location after the 15-s delay. The present experiments were similar to the experiment carried out by Baillargeon and Graber (1988) except that longer delays were used. In Experiment 1, the object remained hidden for 30 s, and in Experiment 2, for 70 s. The results of the experiments yielded evidence that the infants still remembered the object's hiding place after the delays. Such results point to a remarkable gap between search and non-search assessments of 8-month-old infants' location memory. Like the findings of Baillargeon and Graber (1988), the present findings cast serious doubts on accounts that attribute infants' search errors to inadequate memory mechanisms. In the conclusion section, we speculate on alternative explanations for these errors.

Piaget (1954) noted that when infants begin to search for hidden objects, at about 9 months of age, they often search in the wrong location. Specifically, if an

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object is hidden in a location A and, after infants have retrieved it, the same object is hidden in a new location B, infants tend to search for the object in A, where they first found it. Piaget took these perseverative errors to indicate that although infants endow the hidden object with permanence, as evidenced by their willingness to search for it, this permanence is still incomplete. Infants do not conceive of the object as an independent entity whose displacements are regulated by physical laws, but as the extension, or the product, of their action: When the object disappears at B, they search for it at A because they expect that by reproducing their action at A, they will again produce the object. According to Piaget,

> In all the observations in which the child searches in A for what he has seen disappear in B, the explanation should be sought in the fact that the object is not yet sufficiently individualized to be dissociated from the global behavior related to position A. (1954, p. 63)

It is not until infants are about 12 months of age, Piaget maintained, that they come to view the hidden object as a separate entity whose location is independent of their own perceptions and actions.

Over the past three decades, Piaget's observations have been tested by many researchers (see Bremner, 1985; Harris, in press; Sophian, 1984; Wellman, 1985; and Wellman, Cross, & Bartsch, 1987, for recent reviews). These investigators have uncovered several facts about infants' AB errors that are inconsistent with Piaget's account. First, perseverative errors rarely occur when infants are permitted to search immediately after the object is hidden at B; errors occur only when infants are forced to wait before they search (e.g., Diamond, 1985; Wellman et al., 1987). Second, the older the infants, the longer the delays necessary to produce errors (e.g., Diamond, 1985; Fox, Kagan, & Weiskopf, 1979; Gratch, Appel, Evans, Lecompte, & Wright, 1974; Harris, 1973; Miller, Cohen, & Hill, 1970; Wellman et al., 1987). Thus, according to Diamond's (1985) longitudinal study, the delay needed to elicit AB errors increases at a mean rate of 2 s per month, from less than 2 s at 7.5 months to over 10 s by 12 months. Finally, whereas decreasing by 2 to 3 s the delay at which infants produce perseverative errors results in correct responses, increasing this same delay by 2 to 3 s results in random errors, on A as well as on B trials[1] (Diamond, 1985). There is no obvious way in which Piaget's theory can explain these findings.[2]

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[1] This result does not mean that infants who were given only A trials would perform at chance if forced to wait for a period corresponding to the delay at which they produce perseverative errors plus 2 to 3 s. This result only applies to A trials administered in the context of (a relatively long series of) A and B trials. To our knowledge, no one has ever investigated infants' location memory using only A trials.

[2] Another fact that is inconsistent with Piaget's theory is that the frequency of AB errors does not seem to be related to the number of times the object is hidden at A prior to being hidden at B (e.g.,

In recent years, several interpretations have been proposed for infants' search errors (e.g., Bjork & Cummings, 1984; Diamond, 1985; Harris, in press; Kagan, 1974; Schacter, Moscovitch, Tulving, McLachlan, & Freedman, 1986; Sophian & Wellman, 1983; Wellman et al., 1987). One hypothesis has been that these errors reflect the limits of infants' recall memory, with increases in the delay infants tolerate without producing errors corresponding to increases in their retention capacity (e.g., Kagan, 1974). There is a longstanding assumption within the field of infant memory (e.g., Bruner, Olver, & Greenfield, 1966; Piaget, 1951, 1952) that recognition memory is present during the first weeks of life, whereas recall memory does not become operative until late in infancy. Investigations of recognition memory using habituation and preferential-looking paradigms have shown that by 5 months of age infants can recognize stimuli after delays of several hours, days, and even weeks (e.g., Fagan, 1970, 1973; Martin, 1975). These data contrast sharply with those obtained with the AB search task and, it would seem, give credence to the notion that recall memory emerges long after recognition memory and is at first exceedingly fragile, lasting at most a few seconds.

There are serious grounds, however, to doubt explanations of infants' search errors in terms of a late-emerging and easily disrupted recall capacity. Meltzoff (1988) recently reported experimental evidence that young infants can recall information after intervals considerably longer than those used in the AB search task. Meltzoff's study examined delayed imitation in 9-month-old infants. The infants watched an experimenter perform three actions on novel objects; 24 hours later, they were given the same objects to manipulate. The results indicated that half of the infants spontaneously imitated two or more of the actions they had observed on the previous day. This finding (which was supported by findings from control conditions) suggests that by 9 months of age, if not before, infants can recall information after a 24-hour delay.

The hypothesis that infants' perseverative and random search errors reflect the general limits of their recall memory is thus untenable (since infants perform successfully in different circumstances with longer delays). But perhaps this hypothesis could be revised to render it more plausible. One could propose that infants' search errors stem from the absence or the immaturity of a *specific* recall mechanism that is critical for success on the AB task but not on Meltzoff's (1988) delayed imitation task. Comparison of the two tasks suggests several candidate mechanisms. For instance, the AB task requires infants to update the

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Evans, 1973; Landers, 1971; Wellman et al., 1987). Piaget's theory predicts that the greater the number of times infants find the object at A, the more firmly they will associate the search at A with the reappearance of the object, and hence the more likely they will be to search at A on B trials. However, this does not appear to be the case. All other things being equal, infants are as likely to perseverate after receiving 1, 2, 3, or more A trials.

information they have in memory as the object's location is changed; no such updating is needed in Meltzoff's task. A difficulty with this particular candidate, however, is that infants perform well on the AB task with short delays, indicating that they have no trouble updating information.

A more likely candidate for the specific recall mechanism implicated in infants' search errors is an inability to hold updated information in memory. We have just seen that infants have little or no difficulty updating information; and we know from Meltzoff's (1988) data that they can hold information for long delays. Infants' search errors, according to the present hypothesis, would stem from an inability to correctly perform both of these tasks at once.

In recent years, several versions of this hypothesis have been put forth (e.g., Diamond, 1985; Harris, 1973, in press; Schacter & Moscovitch, 1983; Sophian & Wellman, 1983; Wellman et al., 1987). For example, one account of infants' perseverative errors in the AB task assumes that infants can update information about the object's hiding place but can retain this information only for brief delays because of an extreme sensitivity to proactive interference (e.g., Harris, 1973; Schacter & Moscovitch, 1983). According to this view, as infants grow older, they become able to withstand longer and longer delays before the B representation becomes supplanted by the A representation formed on the previous trial. Another account maintains that both the A and the B representations remain available in memory. However, infants rapidly forget or dismiss the fact that the B representation represents the object's *current* location. When deciding whether the object is hidden at A or at B, before engaging in search, infants tend to choose the prior A location because of an inadequate selectivity rule (e.g., Sophian & Wellman, 1983), of a mistaken attempt to infer the object's current location from its prior location (e.g., Wellman et al., 1987), or of an undue reliance on long-term spatial information (e.g., Harris, in press). In each case it is assumed that infants are more likely to choose the correct B location when there is no delay between hiding and search, and that with increasing age, infants choose correctly over increasingly long delays.

Baillargeon and Graber (1988) recently tested the hypothesis that infants' search errors stem from some deficient recall memory mechanism. They reasoned that if infants are unable to update, hold, and selectively attend to information about an object's current location, they should perform poorly in *any* task requiring them to keep track of trial-to-trial changes in an object's location. The task Baillargeon and Graber devised was a non-search task. In this task, 8-month-old infants watched two test events. At the start of each event, the infants saw an object standing on one of two identical placemats located on either side of the infants' midline. After 3 s, identical screens were slid in front of the placemats, hiding the object from the infants' view. Next, a human hand, wearing a long silver glove and a bracelet of jingle bells, entered the apparatus through an opening in the right wall and "tiptoed" back and forth in the area between the right wall and the right screen. After frolicking in this fashion for 15 s, the hand reached behind the *right* screen and came out holding the object, shaking it gently until the end of the trial. The only difference between the two test events was in the location of the object at the start of the trial. In one event (possible event), the object stood on the right placemat; in the other (impossible event), the object stood on the left placemat, and thus should not have been retrieved from behind the right screen. The infants saw the possible and the impossible events on alternate trials (order was counter-balanced) until they had completed three pairs of test trials. The results indicated that the infants looked reliably longer at the impossible than at the possible event. Furthermore, the infant showed the same pattern of looking on all three pairs of test trials. In a second experiment, the hand reached behind the *left* screen for the object; the position of the object during the possible (left screen) and the impossible (right screen) events was thus reversed. The infants again looked reliably longer at the impossible than at the possible event, and did so on all three test pairs. Together, the results of these two experiments suggested that the infants (a) registered the object's location at the start of each trial; (b) remembered this location during the 15 s the hand tiptoed back and forth; and (c) were surprised to see the object retrieved from behind one screen when they remembered it to be behind the opposite screen.

The results of Baillargeon and Graber (1988) indicated that 8-month-old infants have no difficulty remembering trial-to-trial changes in an object's hiding place after 15 s. These results contrast sharply with those obtained with the AB task: 8-month-old infants typically search perseveratively after a delay of 3 s (e.g., Butterworth, 1977; Diamond, 1985; Fox et al., 1979; Gratch & Landers, 1971; Wellman et al., 1987), and search randomly after a delay of 6 s (e.g., Diamond, 1985). Baillargeon and Graber concluded that their findings cast serious doubts on attempts to explain infants' search errors in terms of deficient memory mechanisms. They speculated that researchers needed to consider the *demands of action*—how otherwise adequate memory mechanisms are disrupted or bypassed when actions are required—to account for infants' search errors.

The present experiments built on the results of Baillargeon and Graber (1988). The experiments were similar to the ones they conducted except that longer delays were used. In Experiment 1, the object remained hidden for 30 s, and in Experiment 2, for 70 s. We reasoned that evidence that 8-month-old infants could keep track of trial-to-trial changes in an object's location for such long delays would give strong support to the notion that infants err in the AB search task, not because of memory limitations, but because of difficulties linked to the demands of planning and executing search actions. In addition, such evidence would provide a measure of the magnitude of the gap between search and non-search assessments of infants' ability to remember an object's location. Information about the magnitude of this gap is essential for the elaboration of accounts of the gap's nature, causes, and developmental course.

The method used in Experiments 1 and 2 was similar to that devised by

Baillargeon and Graber (1988) with two exceptions (see Figure 1). First, the infants watched the object for 10 s instead of for 3 s at the start of each trial before the screens were slid in front of the placemats. We thought that the infants might be more likely to remember the object's location after the long delays used in the present experiments if they were given more time to register it. Second, the infants saw the hand tiptoe back and forth during only the last 10 s of the delay between the objects' hiding and retrieval. We were concerned that the infants would become too bored to attend to the events if they watched the hand tiptoe for the entire duration of the delay. During the first 20 s (Experiment 1) or 60 s (Experiment 2) of the delay, the experimenter waved a hand puppet to the side of the screens.

EXPERIMENT 1

Method

Subjects. Subjects were 24 full-term infants ranging in age from 7 months, 21 days, to 8 months, 15 days (mean = 8 months, 1 day). An additional 4 infants were eliminated from the experiment, because of procedural error. The infants' names in this experiment and in the subsequent experiment were obtained from birth announcements in the local newspaper. Parents were contacted by letters and follow-up phone calls. They were offered reimbursement for their transportation expenses but were not compensated for their participation.

Half of the infants were assigned to the right condition, and half to the left condition. For the infants in the *right* condition, the hand reached behind the right screen to retrieve the object; hence, the object was hidden behind the right screen in the possible event and behind the left screen in the impossible event. For the infants in the *left* condition, the hand reached behind the left screen to retrieve the object; the object's position during the possible (left screen) and the impossible (right screen) events was thus reversed.

Apparatus. The apparatus consisted of a wooden cubicle 191 cm high, 100.5 cm wide, and 40 cm deep. The infant faced an opening 43 cm high and 94 cm wide in the front wall of the apparatus. The floor of the apparatus was painted yellow, the back wall was painted green, and the side walls were covered with a patterned contact paper.

Two identical red plastic placemats, each 9.5 cm wide and 11.5 cm long, lay 21.5 cm apart (edge-to-edge) at a distance of 6 cm from the back wall. The left placement was 32 cm from the left wall, and the right placemat was 28 cm from the right wall. Two identical purple screens, each 17.5 cm high and 13 cm wide and made of thick cardboard, stood 2 cm in front of the placemats. The left screen was 31.5 cm from the left wall, and the right screen was 27.5 cm from the right wall. A piece of purple cardboard 2 cm high and 15.5 cm wide connected

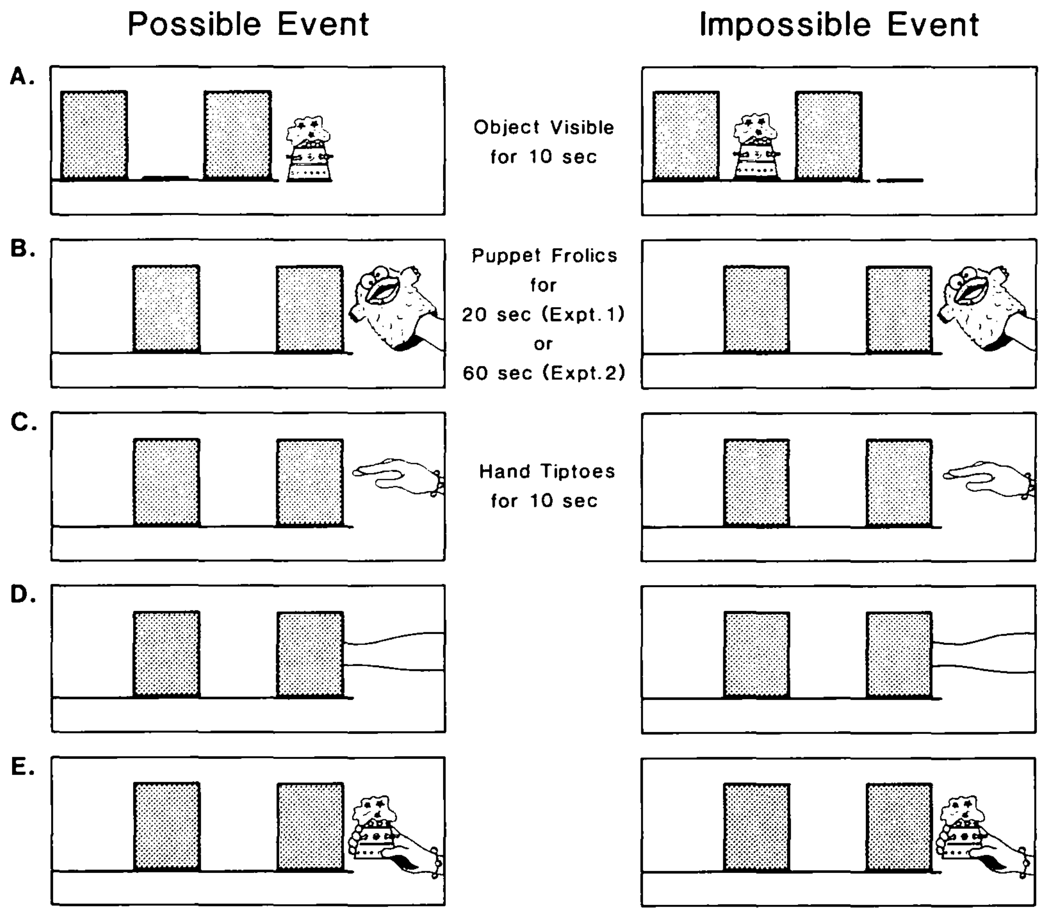

Figure 1. **Schematic representation of the test events shown to the infants in Experiments 1 and 2.**

the lower right corner of the left screen to the lower left corner of the right screen. The screens could be slid toward the left wall (to reveal the placemats) by means of a yellow handle 1.25 cm high and 75 cm long. The right end portion of the handle was glued to the back of the cardboard piece connecting the screens; the left end portion fit between two yellow runners, each 1.25 cm high and 31 cm long, and protruded through the left wall of the apparatus.

The object that was placed on the left or the right placemat during the experiment was an inverted white styrofoam cup decorated with dots, stars, and push-pins. The top of the cup was covered with white cotton balls also decorated with stars. With its decorations, the cup was 12 cm high and 8.5 cm in diameter at its widest point. In the impossible test event, a second, identical object was placed on a cardboard ledge behind the right screen (right condition) or the left screen (left condition). This ledge was 10.5 cm wide and 10.5 cm long and lay on the floor of the apparatus, over the placemat. Whether on the ledge or on the placemat, the object always stood about 3.5 cm behind the screen.[3] In the possible test event, the ledge was folded up against the back of the screen, held in place by a strip of velcro.

During the test events, a human right hand entered the apparatus through an opening 15 cm high and 15 cm wide in the right wall (right condition) or the left wall (left condition). During the first 20 s of the 30-s delay, the hand wore a large hand puppet: a blue, fuzzy "Cookie Monster" or a green, fuzzy "Oscar the Grouch." The two puppets were used on alternate trials; which puppet was used first was determined randomly. During the last 10 s of the delay, the hand wore a silver spandex glove and a bracelet of 5 jingle bells. The glove was 70 cm long and thus covered both the hand and the arm of the experimenter.

The infant was tested in a brightly lit room. Four lights (each with a 40-W lightbulb) were attached to the back and side walls of the apparatus to provide additional light. The lights were arranged so as to eliminate tell-tale shadows. Two wooden frames, each 183 cm high and 70 cm wide and covered with blue fabric, stood at an angle on either side of the apparatus. These frames isolated the infant from the test room. A muslin-covered frame 61 cm high and 94 cm wide was lowered in front of the opening in the front wall of the apparatus between trials.

Right Condition Events. Two experimenters worked in concert to produce the events. The first wore the puppet or the silver glove and manipulated the object; the second operated the screens.

[3] The reader may be concerned that the infants heard the noise made by the ledge rubbing against the floor of the apparatus when the screens were pushed in front of the placemats. This noise was very faint, however, and could not be heard over the much louder noise made by the wooden handle of the screens when pushed against its wooden runners.

Impossible Test Event. The ledge at the back of the right screen lay flat throughout this event and supported one of the objects.

At the beginning of the event, the left screen stood to the left of the left placemat, and the right screen stood to the left of the right placemat. The two placemats and the object standing on the left placemat were clearly visible. After the computer signaled that the infant had looked at the display for 10 cumulative s, the second experimenter slid the screens in front of the placemats, taking about 1 s to complete this movement. Next, the first experimenter inserted her right hand, wearing one of the hand puppets, into the opening in the right wall of the apparatus. The first experimenter positioned the puppet in the area between the right wall and the right screen and made the puppet open and close its mouth, wave, hop, sway, and generally romp in an eye-catching manner. After 20 s, the first experimenter withdrew the puppet, removed it from her hand, and immediately re-entered the apparatus, wearing the long silver glove and the bracelet of jingle bells. The first experimenter's hand tiptoed from the right wall to the right screen and then tiptoed back from the screen to the wall. The first experimenter took about 5 s to tiptoe the distance between the wall and the screen in either direction, resulting in a total tiptoe time of about 10 s. At the end of these 10 s, the first experimenter reached behind the right screen and reappeared holding the object, taking about 2 s to complete these actions. The first experimenter waved the object gently until the computer signaled that the trial had ended (see below). During the last 5 s before the hand reached behind the screen, the second experimenter shook a rattle behind the right half of the apparatus to ensure that the infant was attending to the hand. At the end of the trial, the second experimenter lowered the curtain in front of the opening in the front wall of the apparatus.

To help the experimenters adhere to the schedule just described, a metronome clicked softly once per second throughout the experiment.

Possible Test Event. This event was identical to the impossible event except that the ledge at the back of the right screen was folded up, only one object was used, and this object stood on the right placemat until it was retrieved by the hand.

Left Condition Events. The impossible and the possible events shown to the infants in the left condition were identical to those shown to the infants in the right condition except that the hand entered the apparatus through the opening in the left wall and reached behind the left screen to retrieve the object; the object's position in the impossible (right screen) and the possible (left screen) events was thus reversed.

Procedure. The infant sat on his or her parent's lap in front of the apparatus and faced the area between the screens. The infant's head was approximately 62 cm from the screens. Prior to the experiment, each infant was allowed to inspect the object, which was held by the first experimenter in her gloved right hand. The parent was asked to remain neutral and to close his or her eyes during the trials.

The infant's looking behavior was monitored by two observers who viewed the infant through small peepholes in the cloth-covered frames on either side of the apparatus. The observers could not see on which placemat (left or right) the object was placed and they did not know the order in which the events were presented. Each observer held a button box linked to a MICRO/PDP-11 computer and depressed the button when the infant attended to the events. Inter-observer agreement on each trial was computed on the basis of the number of seconds the two observers agreed on the direction of the infant's gaze out of the total number of seconds the trial lasted (disagreements of less than 0.1 s were ignored). Agreement in this experiment and in the subsequent experiment averaged 93% (or more) per trial per infant. The looking times recorded by the primary observer were used to determine the end of the trials (see below).

The infants saw the impossible and the possible events described above on alternate trials until they had completed four pairs of test trials. Half of the infants in each condition saw the impossible event first, and half saw the possible event first. Each trial ended when the infant (a) looked away from the event for 2 consecutive s after having looked at it for at least 5 s (beginning at the end of the tiptoe phase, when the hand reached behind the screen) or (b) looked at the event for 60 cumulative s (again, beginning after the tiptoe phase) without looking away for 2 consecutive s.

Three of the 24 infants in the experiment contributed only three pairs of test trials to the analyses, 2 because of fussiness and 1 because of procedural error. All infants were included in the data analyses whether or not they contributed the full complement of four pairs of test trials.

Results

The infants' looking times were analyzed by means of a $2 \times 2 \times 4 \times 2$ mixed model analysis of variance with Condition (right or left condition) and Order (impossible event first or possible event first) as the between-subjects factors and with Test Pair (first, second, third, or fourth pair of test trials) and Event (impossible or possible event) as the within-subjects factors. Because the design was unbalanced, the SAS GLM procedure was used to compute the analysis of variance (SAS Institute, 1985). There was a significant main effect of event, $F(1, 134) = 5.42$, $p < .05$, indicating that the infants looked reliably longer at the impossible ($M = 27.7$) than at the possible ($M = 23.2$) event. In addition, there was a significant Order × Event interaction, $F(1, 134) = 13.42$, $p < .0005$. Follow-up comparisons indicated that the infants who saw the impossible event first looked reliably longer at the impossible ($M = 30.7$) than at the possible ($M = 18.7$) event, $F(1, 134) = 17.6$, $p < .00005$, whereas the infants who saw the possible event first tended to look equally at the two events, $F(1, 134) = 1.08$, $p > .05$ (impossible: $M = 24.8$; possible: $M = 27.7$) (see Figure 2). One interpretation of these results is that two factors affected infants' looking behavior: a tendency to look longer at whichever event they saw first, and a tendency to look longer at the impossible event. For the infants who saw the impossible event first, these two tendencies acted in the same direction, resulting in a marked

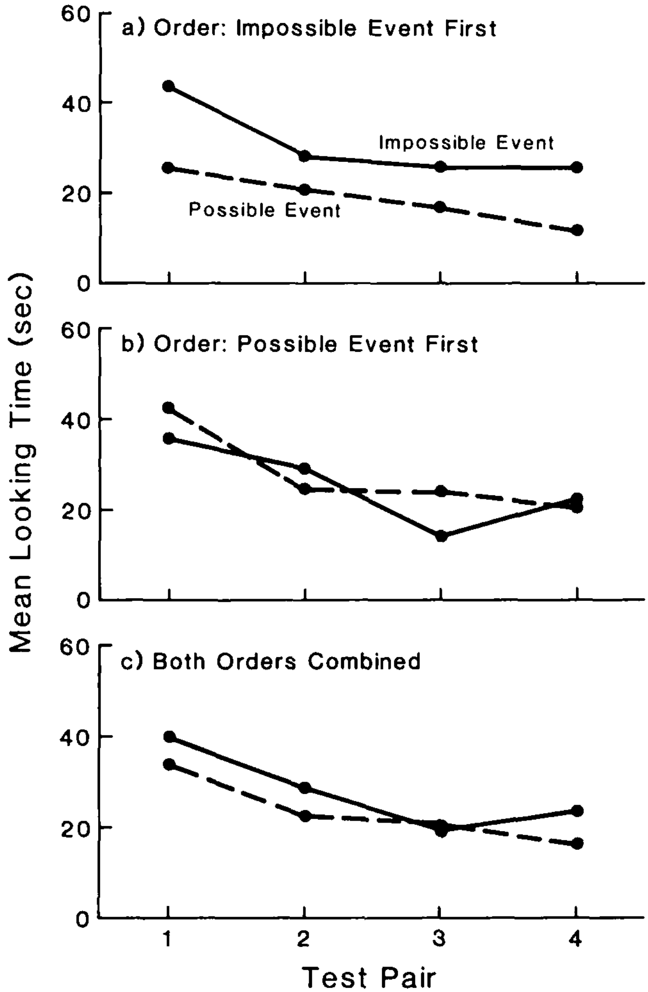

Figure 2. Mean looking times of the infants in the left and right conditions in Experiment 1 to the impossible and the possible test events.

preference for the impossible over the possible event. For the infants who saw the possible event first, the two tendencies acted in opposite directions, thereby canceling each other and leading to statistically equal looking times at the two test events. Such order effects are very common in infancy research (e.g., Baillargeon, 1986).

The initial analysis of variance also yielded a significant main effect of test pair, $F(3, 134) = 15.53$, $p = .0001$, indicating that the infants looked reliably less as the experiment progressed. However, none of the interactions involving the Test Pair factor was significant, all F's < 1.35, indicating that the pattern described above did not differ reliably across the four test pairs.

Discussion

The infants in the right and the left conditions in Experiment 1 looked reliably longer at the impossible than at the possible event. Furthermore, the infants showed the same looking pattern across all four test pairs. These results suggest that the infants (a) registered the object's location at the start of each trial; (b) remembered this location during the 30-s delay; and (c) were surprised to see the object retrieved from behind one screen when they remembered it to be behind the opposite screen.

There is another possible interpretation of the results of Experiment 1. The infants could have looked longer at the impossible event because they (a) believed that the original object was still behind the screen where it had been hidden; (b) assumed that the object retrieved by the hand was a second, identical object; and (c) did not understand how this second object could have been retrieved from a location they remembered as empty. We have no quarrel with this interpretation. Like the interpretation we first proposed, this interpretation assumes that the infants could remember behind which of the two screens the original object was hidden. The only difference between the two interpretations has to do with the infants' construal of the impossible event—whether they believed that the original object magically traveled from one screen to the other without being seen, or whether they inferred that a new object magically appeared behind the empty screen. At this point in time, which construction the infants imposed on the impossible event is of secondary importance; the crucial finding is the infants' memory for the object's initial hiding place.

Like the results of Baillargeon and Graber (1988), the results of Experiment 1 indicate that 8-month-old infants can remember trial-to-trial changes in an object's hiding place after delays considerably longer than those associated with search errors in the standard AB task. Recall that 8-month-old infants typically produce perseverative errors with a 3-s delay and random errors with a 6-s delay (e.g., Butterworth, 1977; Diamond, 1985; Fox et al., 1979; Gratch & Landers, 1971; Wellman et al., 1987). In marked contrast, the 8-month-old infants in the present experiment seemed to have no difficulty dealing with the 30-s delay embedded in the task. This finding lends support to Baillargeon and Graber's

(1988) claim that infants' search errors reflect not inadequate memory mechanisms, as has recently been proposed (e.g., Diamond, 1985; Harris, in press; Schacter & Moscovitch, 1983; Sophian & Wellman, 1983; Wellman et al., 1987), but difficulties linked to the demands of action.

Experiment 2 built on the results of Experiment 1. It tested whether infants could still remember trial-to-trial changes in an object's location when a 70- as opposed to a 30-s delay was introduced between the object's hiding and retrieval.

EXPERIMENT 2

Method

Subjects. Subjects were 24 full-term infants ranging in age from 7 months, 19 days, to 8 months, 21 days (mean = 8 months, 1 day). An additional 5 infants were eliminated from the experiment, 1 because of fussiness and 4 because of procedural error. Half of the infants were assigned to the right condition, and half to the left condition.

Apparatus, Events, and Procedure. The apparatus, events, and procedure used in Experiment 2 were identical to those in Experiment 1 with two exceptions. First, the hand waved the puppet for 60 instead of 20 s, resulting in a total delay of 70 s. Second, the infants received fewer test pairs. Pilot data indicated that the infants tended to become restless and inattentive as the experiment progressed, no doubt because of the long delay between the object's hiding and retrieval. Accordingly, it was decided to administer only two test pairs instead of four as in Experiment 1.

Results

The looking times of the infants in Experiment 2 were analyzed by a 2 × 2 × 2 × 2 mixed model analysis of variance with Condition (left or right condition) and Order (impossible or possible event first) as the between-subjects factors, and with Test Pair (first or second pair of test trials) and Event (impossible or possible event) as the within-subjects factors. The main effect of event was not significant, $F(1, 40) = 1.38$, $p > .05$. However, there was a significant main effect of test pair, $F(1, 40) = 29.47$, $p = .0001$, and two significant interactions: that of Order × Event, $F(1, 40) = 10.62$, $p < .003$, and that of Order × Event × Test Pair, $F(1, 40) = 5.91$, $p < .05$. To study this three-way interaction, an analysis of the simple interaction of Order × Event was conducted for each test pair (Keppel, 1982). The analysis carried out for the first test pair yielded a reliable Order × Event interaction, $F(1, 40) = 16.19$, $p < .0003$. Follow-up comparisons indicated that the infants who saw the impossible event first looked reliably longer at this event ($M = 47.5$) than at the possible event ($M = 35.5$), $F(1, 40) = 5.98$, $p < .02$, whereas the infants who saw the possible event first showed the opposite pattern, $F(1, 40) = 10.52$, $p < .003$ (possible event: $M = 46.2$; impossible event: $M = 30.2$) (see Figure 3). The analysis conducted for the second test pair revealed only a significant main effect of event, $F(1, 40) = 4.95$, $p < .05$, indicating that the infants in both order conditions looked longer at the impossible ($M = 30.3$) than at the possible ($M = 22.6$) event. The Order × Event interaction was not reliable, $F(1, 40) = 0.34$.

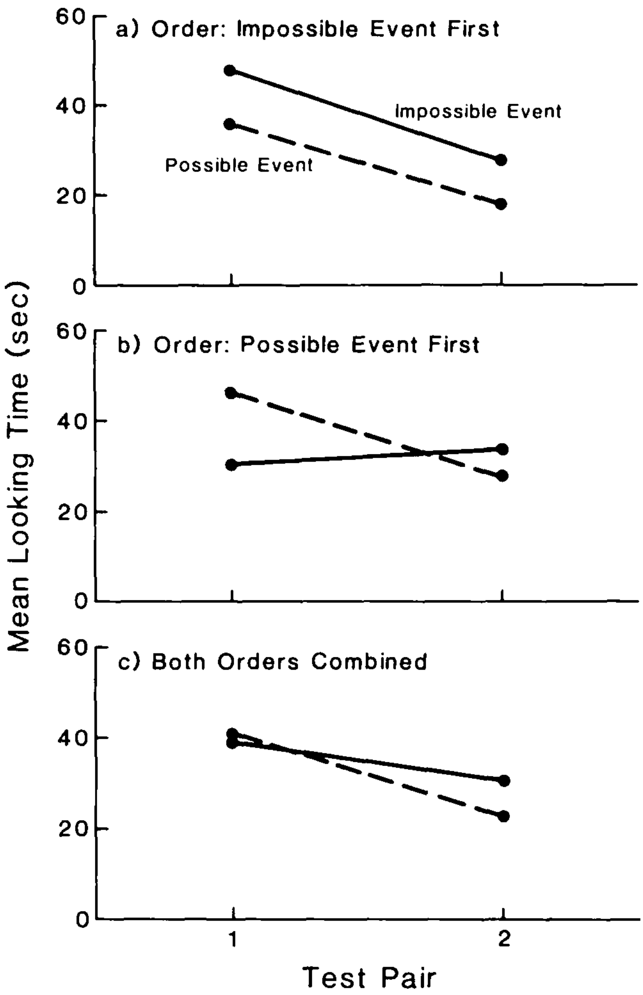

Figure 3. Mean looking times of the infants in the left and right conditions in Experiment 2 to the impossible and the possible test events.

A final analysis was conducted to compare the results of Experiment 2 with those of the fist two test pairs in Experiment 1. This analysis consisted of a 2 × 2 × 2 × 4 × 2 mixed model analysis of variance with Experiment (Experiment 1 or 2), Condition (left or right condition), and Order (impossible or possible event first) as the between-subjects factors, and with Test Pair (first or second test pair) and Event (impossible or possible event) as the within-subjects factors. The main effect of experiment was not reliable, nor were any of the interactions involving this factor, all F's < 2.30. There was a reliable main effect of event, $F(1, 80) = 4.83$, $p < .05$, indicating that the infants looked reliably longer overall at the impossible ($M = 34.2$) than at the possible ($M = 29.9$) event. In addition, there were two reliable interactions: that between Order and Event, $F(1, 80) = 14.54$, $p = .0003$, and that among Order, Test Pair, and Event, $F(1, 80) = 8.27$, $p < .006$. As before, an analysis of the simple interaction of Order × Event was conducted for each test pair. The results of these analyses were very similar to those obtained when examining the data of Experiment 2 alone. The analysis carried out for the first test pair revealed a significant interaction of Order × Event, $F(1, 80) = 22.37$, $p = .00001$. Post-hoc comparisons indicated that the infants who saw the impossible event first looked reliably longer at this event ($M = 45.4$) than at the possible event ($M = 30.3$), $F(1, 80) = 14.59$, $p < .0005$, whereas the infants who saw the possible event first showed the opposite looking pattern, $F(1, 80) = 8.24$, $p < .007$ (impossible: $M = 32.9$; possible: $M = 44.2$). The analysis conducted for the second test pair yielded only a significant main effect of event, $F(1, 80) = 5.94$, $p < .02$, indicating that the infants in both order conditions looked reliably longer at the impossible ($M = 29.2$) than at the possible ($M = 22.4$) event. The Order × Event interaction was not significant, $F(1, 80) = 0.44$.

Discussion

On the first test pair, the infants in Experiment 2 looked reliably longer at whichever event (impossible or possible) they saw first; on the second test pair, they looked reliably longer at the impossible event. This last result suggests that the infants (a) represented the location of the object at the start of the third and fourth trials; (b) remembered this location during the 70 s the object remained out of sight; and therefore (c) were surprised to see the object retrieved from behind one screen when they remembered it to be behind the opposite screen. The results of Experiment 2 are thus consistent with those of Experiment 1 in suggesting that 8-month-old infants can remember trial-to-trial changes in an object's location for delays considerably longer than those associated with perseverative and random errors in the AB search task.

Though similar, the results of Experiment 2 were somewhat weaker than those of Experiment 1. In Experiment 1, the infants showed a reliable overall preference for the impossible over the possible event; in Experiment 2, the infants only showed a reliable preference for the impossible event on the second of the two test pairs. One interpretation for this discrepancy is that a 70-s delay approaches the limits of infants' memory capacity as assessed in the present task; hence, infants are likely to show weaker positive results with such a delay than with the shorter, 30-s delay used in Experiment 1. However, the fact that no reliable differences were found between the data collected in Experiment 2 and those obtained on the first two test pairs in Experiment 1 argues against this interpretation. The absence of reliable differences between these two data sets suggests that (a) had the infants in Experiment 2 been able to attend to four as opposed to only two test pairs or perhaps (b) had a larger number of infants been tested in Experiment 2, a reliable overall preference for the impossible event might have been found in Experiment 2. A non-search task can perhaps be designed that presents infants with long delays but still manages to hold their interest for several pairs of test trials.

GENERAL DISCUSSION

When tested in the standard AB search task, 8-month-old infants typically search perseveratively at A if forced to wait 3 s before retrieving the object (e.g., Butterworth, 1977. Diamond, 1985; Fox et al., 1979; Gratch & Landers, 1971; Wellman et al., 1987), and search randomly at A or B if the enforced delay is increased to 6 s (Diamond, 1985). These findings contrast sharply with those reported by Baillargeon and Graber (1988) and those obtained in Experiments 1 and 2. The 8-month-old infants in these experiments succeeded in keeping track of trial-to-trial reversals in an object's hiding place after delays of 15, 30, and even 70 s.

How can we reconcile the remarkable discrepancy between these two sets of results? The AB search task and the task devised by Baillargeon and Graber (1988) and used in the present experiments differ in several ways. To which of these differences should one attribute the discrepancy in the results? Baillargeon and Graber (1988) argued that the crucial difference between their task and the AB task is that the latter requires infants to engage in manual search whereas the former does not. Two facts support their proposal. One is that investigations of other facets of the development of search have revealed similar lags between cognition and action. For example, there is now evidence that infants understand that an object continues to exist when hidden several months before they begin to search for hidden objects (e.g., Baillargeon, 1987a, 1989, in press; Baillargeon & DeVos, 1989; Baillargeon & Graber, 1987; Baillargeon, Graber, DeVos, & Black, 1989; Baillargeon, Spelke, & Wasserman, 1985; Hood & Willatts, 1986; Spelke, in press). Similarly, there is evidence that infants can infer the location of a hidden object several months before they search successfully on Piaget's (1954) invisible displacement task (Baillargeon, in press). Given these results, it does not seem farfetched that infants would remember the location of a hidden object several months before they search accurately at comparable delays.

The second fact that supports Baillargeon and Graber's (1988) proposal that the absence of search is the critical factor that distinguishes their task from the AB task is that other non-search tasks have yielded converging evidence that infants can remember trial-to-trial changes in an object's location for delays comparable to or longer than those used in the AB task (e.g., Baillargeon, 1986, 1987b; Baillargeon & DeVos, 1989; Baillargeon & Graber, 1988; Baillargeon et al., 1989). For example, in one series of experiments, Baillargeon (1986; Baillargeon & DeVos, 1989) examined 4.5-, 6.5-, and 8.5-month-old infants' ability to remember the location of an obstacle hidden in or out of a moving object's path. The infants sat in front of a small screen; to the left of the screen was a long, inclined ramp. The infants were habituated to the following event: The screen was raised (to show the infants that there was nothing behind it) and lowered, and a toy car rolled down the ramp, passed behind the screen, and exited the apparatus to the right. Following habituation, the infants saw two test events that were identical to the habituation event except that an object (e.g., a box) was hidden behind the screen; this object was revealed when the screen was raised. In the possible event, the object stood in *back* or in *front* of the car's tracks; in the impossible event, it stood on *top* of the car's tracks, blocking its path. The delay between the lowering of the screen and the reappearance of the car from behind the screen (i.e., the delay during which the infants had to remember the object's location in order to be surprised at the impossible event) varied across experiments from about 3 to 6 s. The results indicated that the 6.5- and the 8.5-month-old infants and the 4.5-month-old girls looked reliably longer at the impossible than at the possible event, suggesting that they (a) registered the object's location on each trial; (b) remembered this location after the screen was lowered; and (c) were surprised to see the car reappear from behind the screen when the object blocked its path. These results suggest that infants as young as 4.5 months of age can keep track of trial-to-trial changes in an object's location for delays comparable to or longer than those associated with search errors in infants aged 7.5 months and older.

Although intuitively compelling, Baillargeon and Graber's (1988) case for distinguishing between search and non-search assessments of infants' location memory is inconclusive. Common factors other than the absence of search could be responsible for infants' success in the various non-search tasks devised by Baillargeon and her colleagues (e.g., Baillargeon, 1986, 1987b; Baillargeon & DeVos, 1989; Baillargeon & Graber, 1988; Baillargeon et al., 1989). For example, in Baillargeon's tasks, unlike in the AB task, infants do not see an experimenter hide the object nor do they see the object moved from location A to location B. It is possible (though to our minds unlikely) that these differences rather than the absence of search account for infants' superior performance in Baillargeon's tasks.

This caveat aside, let us consider the hypothesis that infants' search errors reflect difficulties caused by the demands of planning and executing search actions. What could be the nature of these difficulties? One possibility is that, under some circumstances, infants find themselves unable to integrate memory information into the planning of their actions. We specify "under some circumstances" because we already know that (a) infants perform well in the AB task with short delays; (b) infants perform well on A trials with longer delays; and (c) 9-month-old infants can imitate actions (e.g., closing a flap, shaking a plastic egg, depressing a button) after a 24-hour delay (Meltzoff, 1988). These findings suggest that infants' memory is not always disrupted by action—that there are contexts in which infants evince little difficulty using memory information to plan and execute appropriate actions. On this view, further research needs to establish why infants fail to integrate information about an object's hiding place in the planning of an appropriate search action when the object is hidden at a new location *and* a delay of several seconds is imposed before retrieval is allowed.

A second possibility is that the difficulties caused by the demands of action involve infants' problem-solving ability rather than their memory. In order to make clear this second hypothesis, we must first distinguish between two types of problem solving (these two types may constitute opposite ends of a single continuum). One, *reactive* type corresponds to situations in which solutions are produced immediately, without conscious reasoning. Operators—plans or sequences of action—that are stored in memory and whose conditions of application are satisfied are simply "run off" or executed. An example of such problem solving might be reaching for an object whose location is known or driving home along a familiar route. The second, *planful* type of problem solving corresponds to situations in which solutions are generated through an active reasoning or computation process. An example of this second type of problem solving might be finding an object whose location can be deduced from available cues or planning a trip to a novel location. It is assumed that because the second type of problem solving is effortful, individuals use it only when no other avenues are available. Whenever possible, individuals prefer relying on previously computed solutions rather than generating new ones. Hence, when a problem situation is perceived to be similar to a previously experienced situation, individuals will attempt to apply the solution computed in the initial situation, thus engaging in reactive as opposed to planful problem solving (see Logan, 1988, and Suchman, 1987, for interesting discussions of similar concepts).

Let us assume that infants engage in reactive problem solving when no delays or short delays are used in the AB search task, and shift to planful problem solving when longer delays are used (the operators available with short delays may only be applicable when the object's location is visible or when the representation of this location is extremely recent). Thus, with the longer delays, infants would compute a solution on the initial A trial (i.e., determine how to find the object) and store this solution in memory. On the subsequent B trial, instead of re-computing a solution, infants would simply "run off" their previous solution, leading to perseverative errors. It is plausible that the overall similarity of the task context on the A and B trials lures infants into thinking "Ah, ah, I know what to do here!" and into blindly applying what is no longer an appropriate solution.

Some readers may be reluctant to entertain the notion that infants' search errors reflect not difficulties linked to the integration of memory and action but deficiencies in problem solving. However, the latter hypothesis possesses the clear advantage that it can account for data the former hypothesis cannot as easily explain. One such piece of evidence is that infants produce perseverative errors in the AB search task even when the object is visible at B instead of being hidden at B (e.g., Bremner & Knowles, 1984; Butterworth, 1977; Nielson, 1982; see Wellman et al., 1987, for review and discussion). These data create serious difficulties for memory accounts; however, they are easily explained by the hypothesis that infants, instead of performing a close analysis of the task situation and computing the correct solution, are simply repeating a previously successful solution.

A second piece of evidence concerns infant data collected with tasks (a) where no demands are made on infants' memory and yet (b) perseverative errors very similar to those obtained in the AB task are found. Two such tasks are locomotor detour tasks designed by Rieser, Doxsey, McCarrell, and Brooks (1982) and Lockman and Pick (1984). Rieser et al. (1982) tested 9-month-old infants' ability to use auditory information to select an open as opposed to a blocked route to get to their mothers. Each infant and his or her mother sat on opposite sides of an opaque barrier; a side barrier stood perpendicular to the front barrier on the mother's left or right (the position of the side barrier on each trial was randomly determined). The front barrier was sufficiently high so as to hide both the mother and the side barrier from the infant. At the start of each trial, the mother asked the infant to join her behind the front barrier. The mother's calls were differentially reflected on her left and right sides because one side was open and the other side closed. The results indicated that on the initial trial the infants crawled or walked to the open side to find their mothers, suggesting that they detected the auditory cues that specified the location of the side barrier; on subsequent trials, however, the infants merely repeated the left or right direction of their first response. Lockman and Pick (1984) examined 12-month-old infants' ability to go around a barrier by the shortest route to get to their mothers. Each infant and his or her mother were positioned on opposite sides of one end of an opaque barrier (the left and right ends of the barrier were used on alternate trials). The infant could not step over the barrier but could see the mother above it. Lockman and Pick found that on the initial trial the infants chose the shortest route to go to their mothers; on subsequent trials, however, the infants tended to repeat their first response, going to their mothers via the same side across trials.

The results of these two detour tasks are very similar to the results obtained in the AB search task with longer delays. On the initial trial, infants analyze the task situation and compute the correct solution (i.e., determine where to find the object hidden or visible at A, use auditory cues to decide which path to their mother is open and which path is blocked, and select the barrier end that constitutes the shortest route to their mother). On the subsequent B trial, however, instead of reanalyzing the situation and computing a novel solution, infants simply repeat the solution they performed successfully on the previous trial.

A third piece of evidence for the notion that infants' perseverative errors (in the AB task as well as in detour tasks) are due to problem-solving limitations has to do with adult data. Several situations have been identified in which adults will perseverate by applying in one context a solution devised for or learned in another, superficially similar context. A well-known example of this phenomenon is the Luchinses' water jar problem (Luchins, 1942; Luchins & Luchins, 1950; cited in Mayer, 1983). Luchins (1942) wrote: "Einstellung—habituation—creates a mechanized state of mind, a blind attitude toward problem; one does not look at the problem on its own merits but is led by a mechanical application of a used method" (p. 15; cited in Mayer, 1983, p. 54). More recent work by Ross (1984) provides related evidence.

The findings reviewed above lend support to the hypothesis that infants' perseverative errors reflect the limits of their problem-solving abilities. Nevertheless, many questions will need to be addressed before one can admit this hypothesis. First, are we justified in positing two different types of problem solving, one more reactive and the other more planful? If yes, what is the exact nature, scope, and developmental course of each of these types? What are the factors that determine which type of problem solving is likely to be used in a given situation, and how do these factors change with age and experience? The AB search task and the two detour tasks described above share several important features: They are all means–end tasks (i.e., infants perform one action in relation to a first object such as a cover or a barrier in order to perform another action on another object), and they all involve left or right action sequences (i.e., infants search under a left or a right cover and crawl or walk around the left or the right end of a barrier). Are either or both of these features especially likely to create "a mechanized state of mind"? Finally, why did the infants in the present experiments not suffer from the problem-solving deficiencies described above? One possibility is that these deficiencies manifest themselves only when infants must generate as opposed to merely evaluate solutions. In the present task, the infants did not have to generate a solution on each trial for retrieving the object; they only had to judge whether the hand's solution was correct.

Further research will be needed to address these and other questions such as: How can the random errors observed by Diamond (1985) in the AB task with long delays be explained within the present account? And how should one interpret recent findings that success on the AB task is related to infants' self-locomotor experience (e.g., Horobin & Acredolo, 1986; Kermoian & Campos, 1988) as well as to a prefrontal function that matures during the second half of the first year (e.g., Diamond, 1988)? Though it is still unclear what this function consists of, it is worth noting that the prefrontal cortex has long been thought to play a crucial role in the integration of information for and the planning of action (e.g., Diamond, 1988; Fuster, 1980).

The results of the experiments reported in this paper indicate that, when given a task that does not require manual search, 8-month-old infants remember trial-to-trial changes in an object's location for delays 10 to 20 times as long as those that produce perseverative and random errors in the AB search task. These results call into serious questions attempts at explaining infants search errors in terms of faulty or immature memory mechanisms. We have offered a few speculations as to alternative causes for these errors.

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